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Gas recirculation impact on the nitrogen oxides formation in the boiler furnace

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Abstract

The structural features of the fire-tube boilers furnaces are considered. The numerical calculations data of the turbulent combustion in reversing and flow furnaces for gas fuel are presented in the paper. Gas mixture temperature minimum values in volume and nitrogen oxides concentration correspond to the reversing furnace.

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Keywords: fire-tube boiler; reversing furnace; combustion; temperature; nitrogen oxides

1. Introduction

Originally, the steam and hot-water boilers constructions development was carried out in the following two areas: the fire-tube and watertube methods of heat-carrier heating. In the first case combustion products were moving inside the separating surface while water washed the heating surface outside, in the second case the heat carrier moved inside, while exhaust gases did outside.

Combined fire-tube boilers, where the fire tube performed as a furnace while smoke tubes performed as the convection surface, had the greatest heating surface (up to 300 m^2). On exhaust gases circulation there are units having an exhaust gases reverse in the fire tube or double reverse and triple one of the exhaust gases [1,2].

The main toxic component formed at the natural gas and fuel oil combustion in the fire-tube boilers furnaces is nitrogen oxides NO_x. Nitrogen oxides have a negative impact on human health, on the respiratory system in

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particular. Although naturally formed nitrogen oxides quantity exceeds the emissions from human activity results, it is necessary to take into consideration that anthropogenic emissions of nitrogen oxides are localized in the human economic activity places. Therefore NO_x concentration in urban areas is higher than the natural background concentration.

The objective of the study is the gaseous fuel combustion calculation research in the fire-tube boilers furnaces with simultaneous nitrogen oxides emissions limitation. The given processes are still insufficiently studied with regard to the low-powered boilers and attract the particular interest when modern autonomous heat supply sources developing.

2. The nitrogen oxides formation processes modelling

The main toxic component formed at the natural gas and fuel oil combustion in the fire-tube boilers furnaces is nitrogen oxides NO_x. Nitrogen oxides have a negative impact on human health, on the respiratory system in particular [3].

At the fossil fuels combustion in the boilers furnaces, the nitrogen contained in the fuel and air while interacting with the oxygen forms the following oxides: NOx = NO + NO2+ N2O.

The nitrogen oxides NOx main share (95...99 %) formed in steam and hot-water boilers combustion products accounts for nitrogen monoxide (oxide) NO. Dioxide NO_2 and nitrous oxide N_2O are formed in significantly less amounts.

Nitrogen monoxide (oxide) is formed at the fossil fuel combustion both by means of nitrogen oxidation N2 of the air and nitrogen oxidation contained in the fuel. Nowadays three mechanisms, whereby nitrogen oxides are formed: thermal, prompt, fuel ones, are known. At the thermal and prompt NO formation, the source of nitrogen is the air and in case of the fuel NO formation it is nitrogen-containing fuel components [3,4].

3. Methods

To characterize the reacting gases turbulent flows, the turbulence model with two equations is used. In the model the velocity and characteristic length values are defined using various transport equations (hence the term "two equations"). The given turbulence model was named k-ε (k is the turbulent kinetic energy, ε is the kinetic energy dissipation value) [4, 5, 6].

Let's consider the main equations describing reacting gas mixture under the following principal assumptions: gas mixture filling the furnace volume is the grey body; the heat from the torch to the wall is mainly transferred by radiation and convection; inside the boundary layer the pressure does not change along the normal to the body circuit and is equal to the corresponding pressure on the boundary layer external edge; inside the temperature boundary layer, the terms characterizing the energy change in consequence of convection and time variation are of the same order of magnitude with the terms characterizing the energy change as a result of molecular thermal conductivity; the total heat transfer on the gas mixture - wall boundary line is performed by means of the convective heat transfer and radiation; the reacting gas CH_4 – 100 %, oxidizer is air.

- The continuities for the whole mixture:

$$\frac{\partial \rho}{\partial t} + \nabla \bullet (\rho \boldsymbol{U}) = 0 \tag{1}$$

where ρ is the gas mixture density; U is the velocity vector; t is the time.

- The continuities for every component:

$$\frac{\partial(\rho Y_I)}{\partial t} + \frac{\partial(\rho u_j Y_I)}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\Gamma_{Ieff}\frac{\partial Y_I}{\partial x_j}\right) + S_I \tag{2}$$